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An Automated Cloud Observation System (ACOS)

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Howard

Chief Scientist

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20 ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Analysis of cloud base height data collected during a seven-month period from a three Rotating Beam Ceilometer (RBC) network on Otis AFB, Massachusetts, demonstrated the accuracy of an automated cloud observation system. The high degree of correspondence between the automated and human observations of cloud height, low cloud amount, multiple cloud layers, and ceiling confirms the accuracy of the hierarchical clustering technique when applied to a network of RBC's confined to the immediate environs of an airfield. Tests demonstrated only slight improvements in automated cloud observation are

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realized by incorporating additional information from a second and third RBC on or near an airfield.

Preface

This work has benefited from the help of many people without whom successful completion would not have been realized. We are especially grateful to James Bradley for many helpful discussions on AV-AWOS; Capt. James Weyman and Richard Lynch for their solution to automate the rotating beam ceilometer; Leo Jacobs, Ralph Hoar and Clyde Lawrence for maintaining the field test instrumentations; Russell Dengel and Joan Ward for assisting with the data processing; to William Lamkin for preparing the illustrations; and to Karen Sullivan for typing the manuscript.

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An Automated Cloud Observation System (ACOS)

1. INTRODUCTION

The USAF Air Weather Service (AWS) has recognized the need to modernize its basic weather support capabilities. The Automated Weather Distribution System (AWDS) Multi-Command Required Operational Capability (ROC 801-77) calls, in part, for a fully automated airfield *weather observing and* short range forecasting capability at both fixed-base permanent airfields and at bare-base tactical or temporary airfields. In response to these USAF requirements, the Air Force Geophysics Laboratory (AFGL) developed a low-cost, fully automated microcomputer-based system, MAWS (Modular Automated Weather System). The two-year test of MAWS at Scott AFB demonstrated and provided sufficient evidence that the requirement can be satisfied.[1]

Inherent in such an automated airfield observation system is a satisfactory solution to the fundamental cloud base height observation from the rotating-beam ceilometer (RBC). The inability to achieve fully satisfactory automated processing of the RBC signal was one of the shortfalls of the MAWS demonstration. Subsequent to the Scott MAWS demonstration, Weyman and Lynch[2] have developed and

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(Received for publication 16 December 1980)

[1] Chisholm, D.A., Lynch, R.H., Weyman, J.C., and Geisler, E.B. (1980) A Demonstration Test of the Modular Automated Weather System (MAWS), AFGL-TR-80-0087, AD A087070.

[2] Weyman, J.C., and Lynch, R.H. (1981) A Digital Processing and Display System for the Rotating Beam Ceilometer (AN/GMQ-13), in preparation

tested hardware and software refinements which have successfully solved this problem.

The purpose of this study is to develop objective procedures to specify cloud base height(s), low cloud amount categories, and cloud ceiling by expanding upon the basic processing procedures previously developed.[2] The approach taken relies on the methodology initially developed by Duda et al[3] and applied by the National Weather Service in their test of the Aviation Automated Weather Observation System (AV-AWOS).[4] The AV-AWOS test showed good agreement between automated and human cloud observations. The automated values were obtained from a triangular array of RBC's 7 miles apart while the human observations were obtained near the triangle's center point. In the tests conducted here, the average length of the triangle legs is about 1.5 miles. This smaller RBC network, deployed at the AFGL Weather Test Facility (WTF) at Otis AFB, Massachusetts, allowed a further test of the hierarchial clustering algorithm constrained to a typical airfield environment. This report documents a 7-month test of AFGL's Automated Cloud Observation System (ACOS) based on comparisons between ACOS and human observations.

2. HUMAN CLOUD OBSERVATIONS

Federal Meteorological Handbook No. 1 (FMH-1)[5] delineates the procedures to be used in formulating a weather observation, including detailed instructions relating the state or appearance of the sky-to-sky cover by clouds and/or obscuring phenomena. It states "a complete evaluation of sky condition includes the type of clouds or obscuring phenomena present, their stratification, amount, opacity, direction of movement, height of bases, and the effect on vertical visibility of surface-based obscuring phenomena".

The human observer who must describe the state of the sky has a most difficult task. An observer must identify cloud layers, estimate the height of each layer, determine the percentage of sky cover, and identify the type of cloud present. In addition, the observer must determine the amount of sky not visible due to surface-based obscurations and the vertical visibility in the obscuring phenomena. There are several limitations an observer has to work with. Frequently, the observer's view of the horizon is limited by physical obstructions such as an airport terminal

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[3] Duda, R.O., Mancuso, R.L., and Paskert, P.F. (1971) Analysis of Techniques for Describing the State of the Sky Through Automation, Report No. FAA-RD-71-52.

[4] Bradley, J., Lefkowitz, M., and Lewis, R. (1979) Aviation Automated Weather Observation System (AV-AWOS), Report No. FAA-RD-79-63.

[5] NOAA-National Weather Service (1970) Federal Meteorological Handbook No. 1, Surface Observations, U.S. Government Printing Office.

and other buildings. The cloud height measuring device (RBC) is often a mile or more from the observer's location. Hence, the observer is required to determine, through visual observation, the representativeness of the cloud height measurements in the overall observing area. The subjectivity of the process results in a natural variability in cloud observations among observers. While visual acuity, depth perception, and fatigue level play important roles, the so-called packing effect is a substantial contributor to this variability. Here the observer mistakenly incorporates vertical development of clouds into the cloud base extent resulting in an inflated estimate of cloud amount(s). This inherent variability in human cloud observation needs to be recognized in the evaluation of objective and automated techniques. Total replication of human observations should not be anticipated nor sought.

The human observations used in this study were taken by FAA operational personnel located at the opposite side of the airfield on Otis AFB, approximately 1 mile from the AFGL WTF. Supplemental observations, specifically for the purposes of this study, were not obtained due to manpower cost constraints. Rather, we relied on the observations routinely obtained as required by FMH-1, transferred them to computer compatible form and used them in the comparative analysis. Since the RBC is not intended to measure the extent and depth of obscuring phenomena nor to identify cloud type, the automated technique developed and tested in this study was limited to cloud height(s), low cloud amount categories, and cloud ceiling.

3. CLOUD INSTRUMENTATION

3.1 Rotating Beam Ceilometer

The standard AWS cloud-height set (AN/GMQ-13) was used for basic data acquisition in these tests. It consists of a two-lamp projector system, a receiver, and an oscilloscope indicator. The projector has a dual tungsten filament projection system, mechanically modulated at 120 Hz, and continuously rotated at 5 rpm. The receiver is typically set 400 ft from the projector with its field of view vertical and coplanar with the rotating projector beams. The volume of intersection moves upward as each projector beam scans to the vertical. When the volume intersects a cloud, backscatter of the projector beam by particles in the cloud is detected by the receiver and displayed on the indicator in the form of a height vs intensity depiction. The projector angle at which the maximum backscatter return occurs yields the cloud height. Because of known sensor and trigonometric limitations and after an assessment of basic RBC data obtained at Otis WTF, cloud heights in our tests were limited to measurements up to 6000 feet.

In our experiments, both lamps from each RBC were used resulting in ten separate cloud height scans per minute. Two pieces of information were extracted from each scan, the primary or maximum return and the secondary peak. Earlier studies[2] had demonstrated, that when present, the secondary peak can be extracted from the raw RBC signal. Under conditions of variable cloud layers, it may represent useful information in support of aircraft operations and therefore should be used. One aspect of our study was to determine whether or not this secondary peak adds any significant information in the determination of cloud base height or ceiling. We will address this in Section 6.

3.2 Network Spacing

Figure 1 depicts the network of RBC's used in this study. They are separated by distances ranging from under 1 mile to over 2 miles. Two of the RBC's are located at opposite ends of the primary runway on Otis AFB (Runway 05-23) with the third one at the AFGL WTF. As stated before, this RBC layout allowed us to test the clustering technique in a typical airfield real estate configuration and to determine therein the additive utility of multiple RBC's in specifying cloud characteristics. Note also the location of the FAA Control Tower from which the regular cloud observations were obtained.

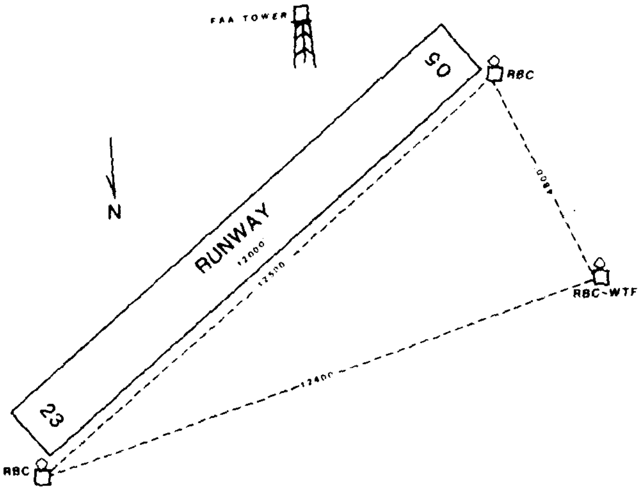

Figure 1. Otis AFB RBC Configuration

4. AUTOMATED CLOUD PROCESSING

4.1 Preprocessing

The initial processing of RBC data was accomplished with the MAWS-type data processing system which supports AFGL's WTF.[2] Values of cloud base height

(CBH) were obtained independently from three RBC's at Otis and recorded on magnetic tape at AFGL. Each RBC lamp yields two CBH values per scan (five scans per minute). For each scan of each lamp, the magnitude of the peaks are rank ordered and the two largest peaks retained as CBH's, listed as Max1 and Max2 in Table 1. Also, a 1-min mean CBH value is objectively determined for each lamp based on the five Max1 values obtained during the current minute and, in certain situations, during the observation obtained during the previous m[illegible]. A value of 10000 signifies a CBH was not obtained and 15000 means a second maximum was not detected.

The cloud heights in the example shown in Table 1 bring out several points. First, systematic differences between the readings of LAMP1 vs LAMP2, as in the case of the R2[illegible] RBC, can be due to hardware limitations of the RBC such as misalignment or alignment which can only be achieved to an accuracy of approximately 1 degree. This 1 degree of uncertainty can result in several hundred feet differences from one lamp to another at high elevation angles (above [illegible]). Second, the presence of scattered or fractured cloud layers separate from the main cloud mass can be accounted for (in this case, some scud clouds are clearly present at about 600 ft below the main cloud layer near 4000 ft). Finally, internal consistency among scans of a particular lamp and between RBC's can be substantiated.

4.2 Automated Cloud Observation Determination

The method of incremental clustering, described by Duda et al.,[3] has been used in this study. Clustering is first done independently for each RBC using a 30-min file of cloud heights. The independently clustered data were then combined into cloud estimates. Although the operational observations are normally available on an hourly basis, the clustering algorithm was executed every minute [illegible] weight is given to the latest 10 [illegible] rapidly [illegible] compensates for the [illegible] the FMH [illegible] in relation to [illegible].

[illegible] These include the number of ceilometers, the number of lamps per ceilometer, the use of [illegible] value, or the use of the [illegible] beams, or the use of the two maxima, and the maximum number of events or observations obtained in the [illegible] sample. The use of a 30-min sample yields a sample size of at least [illegible] counts for the clustering algorithms to operate on. This is the minimum sample [illegible].

Table 1. Raw RBC Data

	R05				R23				WTF			
	LAMP1		LAMP2		LAMP1		LAMP2		LAMP1		LAMP2	
	Max1	Max2	Max1	Max2	Max1	Max2	Max1	Max2	Max1	Max2	Max1	Max2
Minute	4155		3972		4814		3806		4353		4155	
Scan 1	3972	507	4155	15000	4814	15000	3806	15000	4353	15000	10000	15000
Scan 2	4155	15000	3972	15000	4814	15000	3806	15000	4353	15000	4155	15000
Scan 3	4353	604	3972	517	4814	582	3972	15000	4155	15000	4155	15000
Scan 4	4353	15000	587	15000	5082	582	4155	15000	4353	15000	4155	15000
Scan 5	4155	15000	3806	15000	5082	15000	4155	15000	4353	15000	4155	15000

Table 2. Methods of Grouping Ceilometer Data

Method	Number of Ceilometer	Number of Lamps per Ceilometer	Minute Value	Scans Values Max1	Scans Values Max2	Maximum No. Events
1	1	2	X			80
[illegible]	1	1		X		[illegible]
[illegible]	1	1			X	400
[illegible]	[illegible]	[illegible]		X		[illegible]
[illegible]	[illegible]	[illegible]			X	[illegible]
[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]			X	[illegible]
[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]		X		[illegible]
[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]			X	[illegible]
[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]			X	[illegible]

[illegible]

[illegible]

layers, the accumulated number of events up to and including the layer are used to classify the cloud amount category for the higher layers. Based on data collected at Otis, we modified the AV-AWOS population proportions to 0.04, 0.51, and 0.85 as break points from clear to scattered (SCT), scattered to broken (BKN) and broken to overcast (OVC). Figure 3 is an example of output of the clustering technique with cloud observations (heights and amounts) plotted at a 3-min interval for over a 16-hr period. It clearly demonstrates the ability of the clustering technique to handle multiple layer and evolving cloud conditions with outcomes internally consistent and meteorologically sound. The corresponding human observations, plotted along the time axis, demonstrate the automated technique's capability to handle this complex situation. In fact, the automated technique identified major changes (improvements) in ceiling conditions well before the human observations become officially recorded, particularly after darkness fell. Table 3 is an example of output for an ACOS observation.

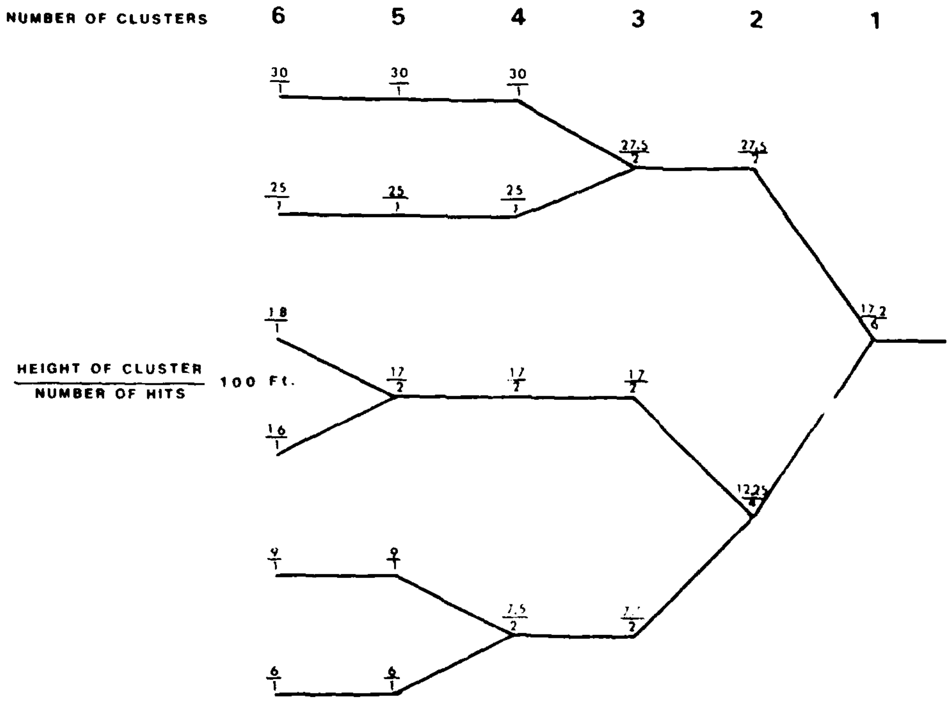

Figure 2. Example of Hierarchical Clustering

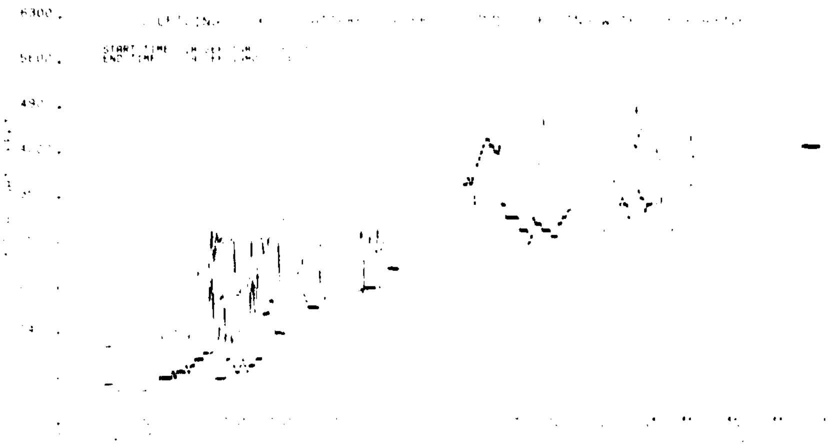

Figure 3. Time Series of ACOS and Human Observations

Table 3. ACOS Sample Output

Time (GMT)	Cloud Observation		
80 Sept 18/1618	11 SCT	18 BKN	24 OVC
80 Sept 18/1621	11 SCT	18 BKN	25 OVC
80 Sept 18/1624	11 SCT	23 BKN	31 OVC
80 Sept 18/1627	11 BKN	25 OVC	
80 Sept 18/1630	7 SCT	11 BKN	30 OVC
80 Sept 18/1633	7 SCT	11 BKN	28 OVC
80 Sept 18/1636	7 SCT	19 BKN	29 OVC

5. DATA SETS

Cloud-height data were collected from March through October 1980. In all, forty-one episodes were selected for this experiment with approximately 600 comparisons made between the automated and human observations. No comparisons were made between the human and automated observations if an obscuration was reported by the human observer. Episodes were selected which met the following criteria: (1) the episode length was at least 2 hrs in duration, (2) at least one of the three RBCs was operating, and (3) scattered or more clouds below 600 ft were reported by the FAA observer. Table 4 summarizes the relative frequency distribution (RFD) of the automated cloud observations for the forty-one episode data set.

While there were just under 600 human observations in the full data set, there were over 15,500 automated observations generated from the RBC data.

Table 4. Automated Observation Data Relative Frequency Distribution (%) for Method No. 12

Category	No. Obs	RFD (%)
CIG < 200	[illegible]	4.2
200 ≤ CIG < 500	[illegible]	[illegible]
500 ≤ CIG < 1000	[illegible]	[illegible]
1000 ≤ CIG < 3000	[illegible]	23.1
3000 ≤ CIG ≤ 6500		
UNL	[illegible]	[illegible]
NO CIG		

6. COMPARATIVE ANALYSIS

Data are presented in this section to answer the following questions:

(1) To what extent are specifications different based on indicated [illegible] [illegible] as compared to human [illegible]?

(2) To what extent does the use of cloud scan data from two levels (layers) [illegible] [illegible] [illegible]?

(3) How well [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] single layers, [illegible] [illegible]?

(4) [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] appr[illegible]

[illegible] observations [illegible] [illegible] [illegible] [illegible] [illegible] automated observations [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] the experiment relied solely upon the routine, once [illegible] hourly observations taken by the control tower personnel. A special human observation set would have generated considerably more observations if it [illegible] [illegible] [illegible] [illegible] [illegible] constraints. Table [illegible] lists the number of comparisons for [illegible] [illegible] method. [illegible] smaller number of comparisons for [illegible] [illegible] [illegible] RBC outages encountered during the episodes. In some [illegible], [illegible] [illegible] were inoperative for short periods of time while in others one of them was not available at any time. Of the forty-one episodes used, only ten episodes (spanning 266 hrs of comparisons) included data from all three RBC's.

Table 5. Sample Sizes for Comparative Analysis

Method	Number of Comparisons
1-5	594
6-10	323
11-15	266

Questions 1 and 2 above were addressed using the subset of data for which a ceiling condition (more than 50% cloud cover below 3000 ft) was determined to exist by either the FAA observer of the automated procedure (ACOS). Table 6 lists the percentage of agreement realized by each of the fifteen methods of grouping ceilometer data (see Table 2 for description of grouping criteria). Regarding the comparison of individual scan data to 1-min mean values note the difference between Method 2 vs 1, 7 vs 6 and 12 vs 11. The results suggest nothing has been lost by preprocessing cloud scan data into 1-min mean values for the clustering algorithm. Recall the algorithm development has been structured to use a weighted 30 min of data to provide the possibility of 80 events occuring when 1-min means are employed. This number of events ensures sampling stability consistent with the recommendation of Duda et al.[3] These results confirm that stability, and demonstrate only marginal additive contribution using the greatly increased number of events in individual scan data. Results of Methods 2 and 3, 7 and 8, and 12 and 13 demonstrate secondary peak information does not contribute to improved specification. The slight decrease in agreement resulting from the "two-lamp" algorithms as compared to analogous "one-lamp" algorithms (for example, Method 5 vs Method 3) is probably related to lamp misalignment within one or more RBC's. This can result in cloud heights from the two lamps being sufficiently different to alter the cloud amount determination in situations bordering on the threshold of a ceiling condition (that is, 5/10th cloud cover ± 0.05).

One can assess the additive effect to ceiling specification of multiple RBC's by comparing results across any one row of Table 6. For example, Methods 1, 6 and 11 are all based on the use of 1-min mean cloud base height data as provided by the preprocessing procedure,[2] while Methods 5, 10 and 15 are based on the primary and secondary peak values from each scan. In each instance, a slight increase in agreement is realized by adding a second RBC and then a third RBC. This suggests that at airfields with two RBC's presently installed, both could be utilized with a modest increase in confidence in automated cloud observations. Equally important, if not more so, automated cloud observations from a single RBC have been shown to have substantial agreement with human observations under most weather situations. This study has demonstrated (confirming the earlier AV-AWOS findings^4), the added investment into a second or third cloud base height sensor in the immediate vicinity (within 2 to 3 miles) of an airfield is not warranted for automated cloud observation purposes except, perhaps, in unusually complex cloud regimes or locations.

Table 6. Joint Occurrence of Ceiling Reports (All Cases)

1-RBC		2-RBC's		3-RBC's	
Method	Percent	Method	Percent	Method	Percent
1	84.3	6	86.4	11	[illegible]
2	84.2	7	86.3	12	[illegible]
3	85.2	8	[illegible]	13	90.8
4	83.6	9	[illegible]	14	88.6
5	83.8	10	86.4	15	[illegible]

Figure 4 is a time series plot of a complex low cloud episode at the OTIS WTF on 18-19 September 1980. It demonstrated the correspondence between ceiling height determination is greater at lower heights (below 3000 ft) or elevation angles. When the joint occurrence statistics shown in Table 6 are computed based only on ceilings below 3000 ft, the percentages increase about 2 to 4 percentage points, on average, for each of the methods tested. Above 3000 ft the differences tend to be greater due to the human observer having more difficulty visually extracting the "correct" elevation angle. At high elevation angles (for example, above [illegible]), small angle differences correspond to large height differences. Nonetheless, these data clearly demonstrate the representativeness of the clustering algorithm procedure for determining ceiling height.

Table 7 summarizes the percent frequency distribution of low cloud amount categories based on 1-min mean values for the 1-, 2-, and 3-RBC automated procedures vs the FAA observations. The within-table percentages are of the total sample. The aggregate off-diagonal percentages are shown in parentheses. The TOT column and row also contain percentages of the total sample. Regardless of whether 1-, 2-, or 3 RBC's are used in the automated procedure, low cloud amount conditions are underspecified by about 15 percentage points (25% below the diagonal vs 10% above in the 1-RBC case). This impacts about 10% of the ceiling determinations (for example, in the 1-RBC case, human observations denote ceiling conditions 89% compared to 79% for the automated method). The difference can be due to deficiences in the method by which the automated procedure deduces cloud amount from the frequency of occurrence of cloud height data (or population proportions as discussed in Section 4.2). Further refinement of the selected breakpoints between cloud amount categories could be accomplished beyond the modification to the AV-AWOS recommended values done in this study. For the purpose of this study, however, additional refinement is not felt to be necessary. Conversely, the differences could be due to biases in the human observations caused by confounding cloud patterns, contrast and illumination uncertainties (especially after darkness), or the press of other responsibilities impacting on the time spent preparing the cloud observations. Note also that, for the cloud episodes used in this study, the human observation data set contained 2% or less clear conditions below 6000 ft while 8% of the automated observations indicated clear conditions. This can be attributed to distant, lower level clouds beyond the range of the three RBC's but observable by the tower personnel.

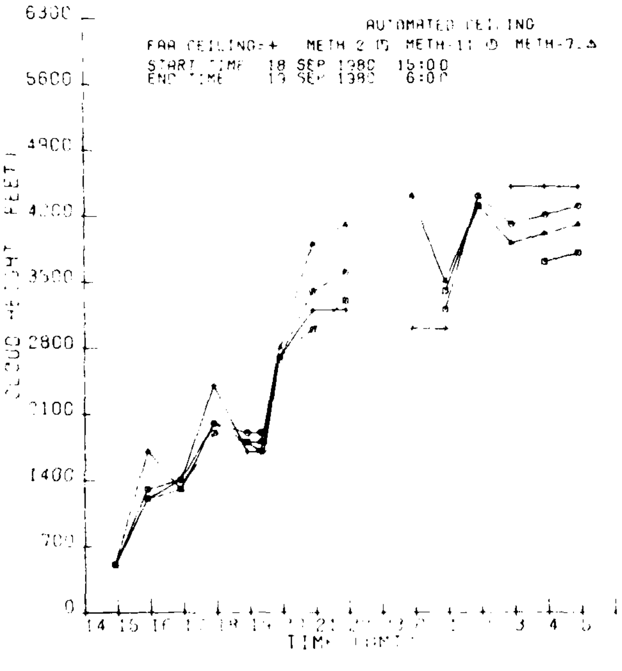

Figure 4. Time Series of ACOS and Human Observations (Ceiling)

Table 7. Contingency Tables Comparing Percent Relative Frequency of Low Cloud Amounts

	Automated Procedure														
	1-RBC					2-RBC's					3-RBC's				
Human Observation	CLR	SCT	BKN	OVC	TOT	CLR	SCT	BKN	OVC	TOT	CLR	SCT	BKN	OVC	TOT
CLR	1				2	1				1	0				1
			(10)					(7)					(8)		
SCT		4			9		5			12		6			11
BKN			5		21			5		17			5		17
	(25)					(25)					(29)				
OVC				55	68				57	70				52	71
TOT	8	13	16	63	100	8	14	15	63	100	5	16	20	59	100

Table 8 shows the percent relative frequency distribution of the number of cloud layers below 6000 ft reported by the human observers and the automated procedures based on 1-min mean values (Methods 1, 6, and 11). Here again, we find a tendency for the automated technique to underspecify cloud conditions. Note in the 1-RBC case, 25% of the observations fell below the diagonal indicating more cloud layers in the human observations than in concomitant automated observations while only 15% fell above the diagonal. The relative distribution of the number of cloud layers, as reflected in the column and row totals is without the bias reflected in the cloud amount category evaluation. Refer to Figure 2 for an example of the meteorological consistency and representativeness of the automated cloud observations in a multi-layered cloud regime.

The results in Tables 7 and 8 support the general finding presented earlier that cloud specification is not improved substantially by adding basic cloud height information from a second or third RBC in the immediate vicinity of the airfield. While, in most situations, a second RBC's data will not contribute to specification improvement, for certain multi-layered and variable cloud conditions it will have a positive, stabilizing effect on the cloud characteristics determination.

7. SUMMARY AND CONCLUSIONS

Analysis of cloud base height data collected during a seven-month period from a three RBC network on Otis AFB, Massachusetts, demonstrated the accuracy of an automated cloud observing system. The high degree of correspondence between the automated and human observations of cloud height, low cloud amount, multiple cloud layers, and ceiling confirms the accuracy of the hierarchical clustering technique when applied to a network of RBC's confined to the immediate environs of an airfield. Fifteen methods of combining basic cloud-height data were formulated and tested on data gathered for forty-one episodes of extensive low cloudiness. These tests demonstrated only slight improvements in automated cloud observation are realized by incorporating additional information from a second and third RBC on or near an airfield. In addition, there is a non-significant difference in test results when peak returns or multiple returns from individual cloud height scans are used instead of 1-min mean cloud height data sets. Based on comparisons with operationally-obtained human observations, the automated techniques underspecify cloud amount categories and the number of low cloud layers by about 10-1. percent.

Table 8. Contingency Tables Comparing Percent Relative Frequency of Low Cloud Layers

		Automated Procedure														
		1-RBC					2-RBC's					3-RBC's				
Human Observation		0	1	2	3	TOT	0	1	2	3	TOT	0	1	2	3	TOT
	0	1				2	1				1	0				1
					(15)					(20)					(11)	
	1		50			68		47			71		53			67
	2			8		26			9		24			10		27
		(25)					(23)					(25)				
	3				4	4				0	4				1	5
	TOT	8	68	20	4	100	8	61	27	4	100	5	72	20	3	100

It is concluded, based on these tests and earlier tests of the AV-AWOS system, that automated procedures based on hierarchical clustering yield stable, reliable and representative standard cloud observations. The ability to successfully interface the RBC and continuously process its output with a microprocessor-based system has been demonstrated in these tests and earlier ones.[2] Whether used as a basic stand-alone automated cloud observation module or as a real-time support to human observers, modernization of the cloud observing function can be undertaken, even with exceptionally mature sensors like the RBC.

The hierarchical clustering technique is being integrated into the MAWS at the AFGL WTF as a part of a continuing investigation of short range prediction systems. Specifically, an automated short-range forecasting (30 to 180 min) experiment is underway utilizing the automated observations as the development sample. Forecasts of cloud ceiling will be made in probabilistic and categorical format.

References

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Appendix A

ACOS Algorithm

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$$D^2 = \frac{N(J) \times N(K)}{N(J) + N(K)} \times [H(J) - H(K)]^2$$

where

D = Least square distance,

H = Cluster height,

N = Number of cloud hits in cluster.

(e) If there are more than four clusters combine the two clusters with the smallest least square distance between them. Clusters are combined in height as follows:

$$H(L) = \frac{[N(J) \times H(J)] + [N(K) \times H(K)]}{N(J) + N(K)} ,$$

and

$$N(L) = N(J) + N(K) .$$

(6) The H(L) and N(L) cluster replaces the [H(J), N(J)] and [H(K), N(K)] cluster pair.

(7) Clustering continues; Return to Step 5 .

(8) After clustering determine if clusters from the same ceilometer can be combined as follows:

(a) Group clusters in ascending order.

(b) [illegible]

(c) If [illegible] lowest [illegible] 1000 [illegible] between heights [illegible] less, [illegible]

(d) If lowest [illegible] 1000 [illegible]

If lowest [illegible] 3000 [illegible] between heights is 1000 [illegible] less, [illegible]

[illegible] RBC [illegible]

[illegible]

(11) Round cluster heights to:

Surface to 5000 ft: nearest 100 ft,

5000 to 6000 ft: nearest 500 ft.

(12) Sky cover shall be calculated by using the following criteria:

(a) Cloud cover factor (R_L) is calculated starting with the lowest cluster (layer)

$$R_L = \frac{\sum_{L=1}^{n} \text{(Total Number of Layer Hits)}}{\text{(Total Possible Hits)}}$$

where n is the cluster order starting from the lowest layer. For subsequent layers ($L > 1$), the summation principal from FMH-1 is applied,

(b) If less than five hits from all ceilometers, "CLR BLO 60" is stored,

(c) If $R_L \leq 0.04$, height and "scattered" is stored,

(d) If $R_L \leq 0.85$, height and "broken" is stored,

(e) If $R_L > 0.85$, height and "overcast" is stored.

(13) Cloud data is displayed as follows:

(a) Clear is printed if no clouds,

(b) If one layer, report it,

(c) If two or three layers, report them with only one overcast layer,

(d) If there are more than three layers, a total of three layers is reported in the following order:

(1) lowest scattered,

(2) lowest broken.

(3) lowest overcast.

(14) Generate a new observation every minute.